Stream Network and Watershed Delineation using Spatial Analyst Hydrology Tools

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1.0 Purpose

The purpose of this exercise to demonstrate the steps involved in delineating a stream network and watershed boundaries from a digital elevation model (DEM) using the Spatial Analyst Hydrology Tools in ArcGIS.

2.0 Computer Requirements

You must have a computer with windows operating system, and the following programs (extensions) installed:
1. ArcGIS 9.3
2. Spatial Analyst Extension

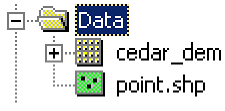
3.0 Data Requirements and Description

The data files used in the exercise consist of DEM grid for Cedar Creek in northeast Indiana and the hydrography data (mainly stream network and outlet points). A tutorial that describes how to download and process DEM data is available at the following link

http://web.ics.purdue.edu/~vmerwade/education/dem.pdf

It is highly recommended that you go through the exercise of downloading the data to make yourself aware of the procedure involved.

Download the data from ftp://ftp.ecn.purdue.edu/vmerwade/download/data/hydrology.zip. **Unzip** *hydrology.zip* in your working directory. The ArcCatalog view of the data folder is shown below:

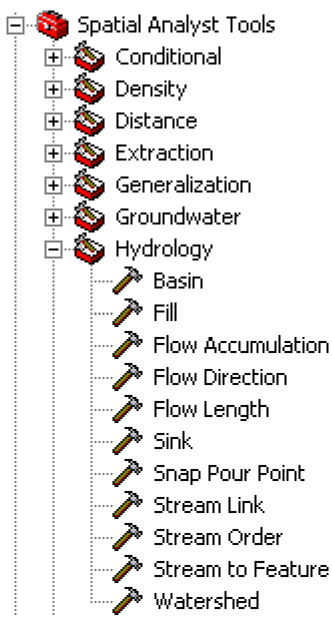


cedar_dem is a 30 DEM obtained from USGS and clipped for the study watershed (Cedar Creek). The second dataset, *points.shp*, is a shapefile containing points for which sub-watersheds will be delineated in this tutorial. Both *cedar_dem* and *point.shp* are already assigned a projected coordinate system (NAD_1983_UTM_16).

Note: It is very critical to assign and use consistent coordinate system for all the datasets used in delineating watersheds by using any pre-processing tool.

4.0 Getting Started

Open ArcMap and save it as hydrology.mxd. All spatial analyst tools that are used for delineating stream network and watershed boundaries are available in ArcToolbox. If ArcToolbox is not activated within the map document, click on the ArcToobox button to access the tools. Hydrology tools can be found by selecting Spatial Analyst Tools→Hydrology within ArcToolbox as shown below:

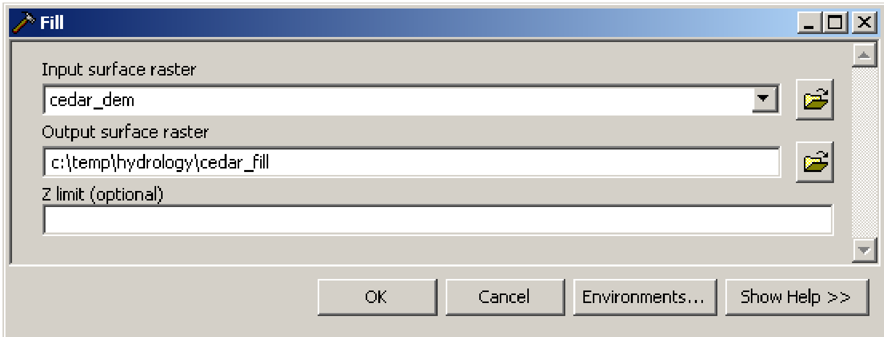


Now add cedar_dem to the map document. This is the only dataset you will need to get started with the process. We will add other datasets later in the tutorial.

5.0 Filling Sinks

This function fills the sinks in a grid. If cells with higher elevation surround a cell, the water is trapped in that cell and cannot flow. The Fill Sinks function modifies the elevation value to eliminate this problem.

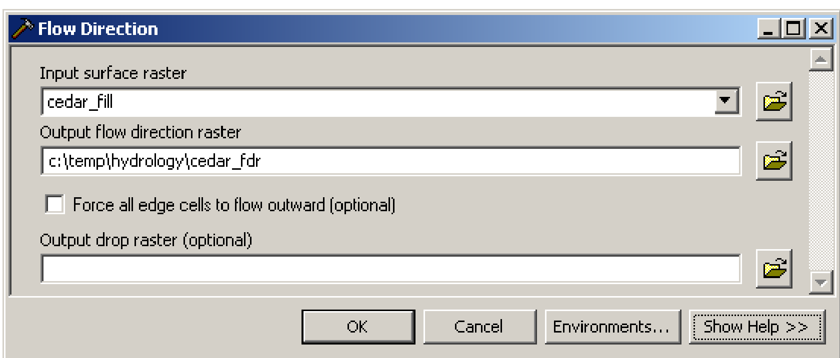
Double click on the Fill tool. Provide cedar_dem as the input surface raster and save the output raster as cedar_fill in your working directory. The main function of this tool is to remove imperfections in the DEM to enable waterflow to the watershed outlet. However, if there are natural sinks in the data (e.g, 10m deep lake), you can use the “Z limit” to retain these natural sinks. For example, if you specify Z limit as 6m, the program will not fill any sinks that are deeper than 6m. The default is to fill all sinks (do not provide any input for Z limit). Click OK.



After the process is complete a filled DEM (cedar_fill) will be added to the map document.

6.0 Flow Direction

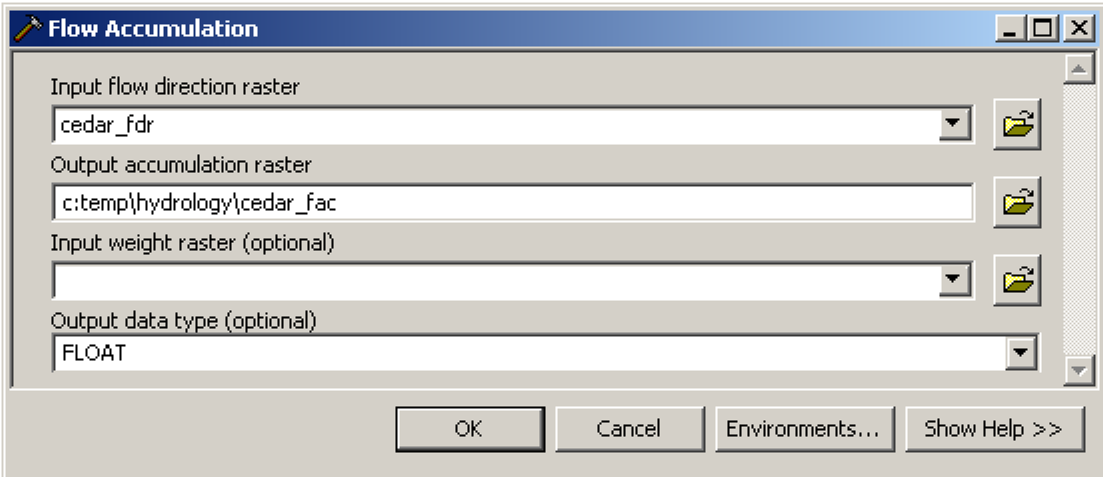
This function computes the flow direction for a given grid. The value in any given cell of the flow direction grid indicates the direction of the steepest descent from that cell to one of its neighboring cells using eight direction pour point (D8) method. Double click on Flow Direction tool. Select cedar_fill as the input surface raster and name the output raster as cedar_fdr. Leave the other optional inputs unchanged. Click OK.



After the process is complete, a flow direction grid with cells having one of the eight flow direction values (1,2,4,8,16,32,64,128) will be added to the map document. Save the map document.

7.0 Flow Accumulation

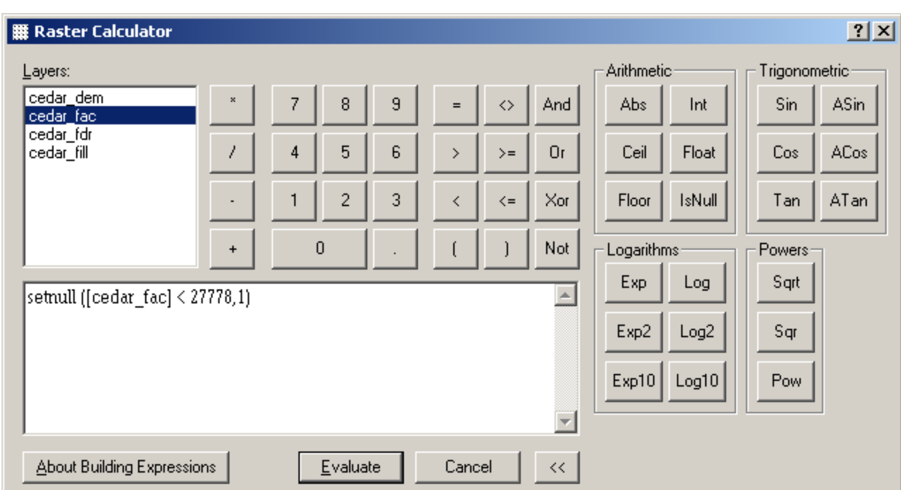
The function uses the flow direction grid to compute the accumulated number of cells that are draining to any particular cell in the DEM. Double click on Flow Accumulation tool. Select cedar_fdr as the input flow direction raster, and save the output flow accumulation raster as cedar_fac. Leave the default options for input weight raster and output data type (float) unchanged. Click OK.



After the process is complete, a flow accumulation grid will be added to the map document. You will clearly see a stream network in this output, and if you check the pixel value (by using the identifier tool), the values along the cells that appear to form a stream network will have much higher values compared to the surrounding cells. Save the map document.

8.0 Stream Network

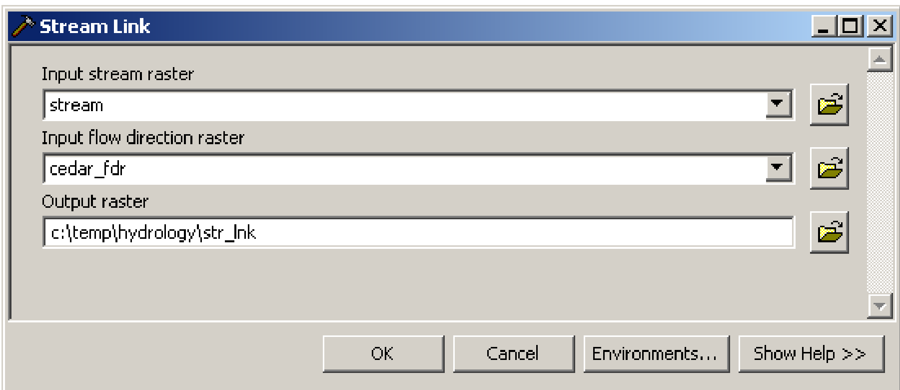
Because the flow accumulation gives the number of cells (or area) that drain to a particular cell, it can be used to define a stream. It is assumed that a stream is formed when a certain area (threshold) drains to a point. This threshold can be defined by using the number of cells in the flow accumulation grid. If we assume an area of 25km2 as the threshold to create a stream, the number of cells corresponding to this threshold area is 27,778 (25000000/(30*30)). To create a raster, that will have stream cells corresponding to a threshold area of 25km2, select spatial analyst→Raster Calculator. Create a raster from cedar_fac such that it only includes cells that have pixel value greater than 27778 as shown below, and click Evaluate.



This will create a calculation raster where all the cells with value greater than or equal to 27778 in cedar_fac will have a value of 1, and all other cells are set to Null. Make the "calculation" raster permanent right-clicking on it and selecting Data→Make Permanent. Save the permanent raster as stream in your working directory. Remove calculation, and add stream to your map document. Save the map document.

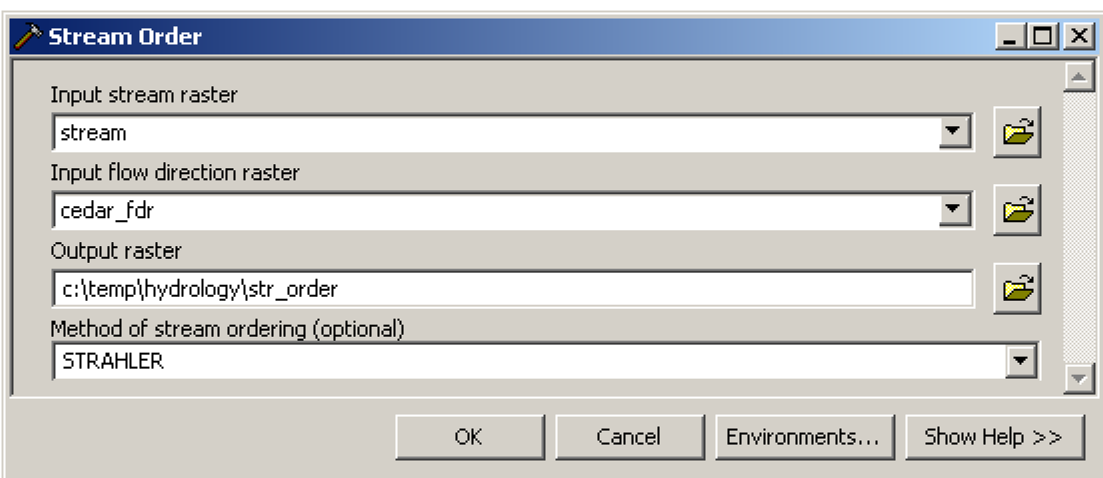
9.0 Stream Link

This tool assigns a unique number to each link (or segement) in the stream raster. Double click on Stream Link. Provide stream as the input stream raster, cedar_fdr as the flow direction raster, and name the output raster as str_link.



10.0 Stream Order

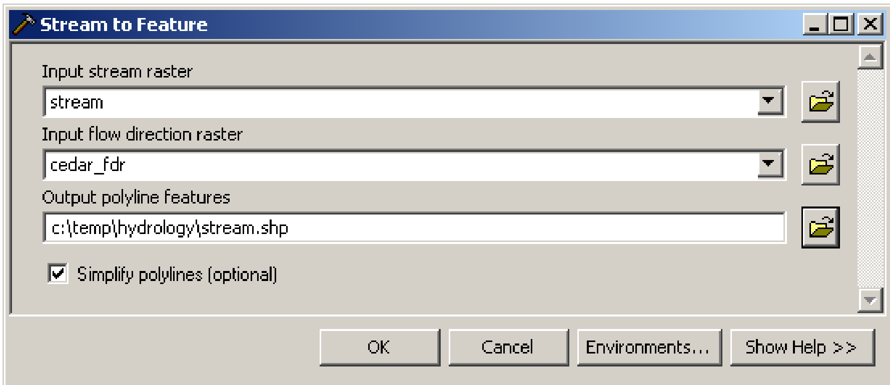
This tool creates stream order for the stream network. Double click on stream order. Provide stream as the input for stream raster, cedar_fdr as the input for flow direction raster and name the output raster as str_order as shown below. Two methods are available for estimating stream order. Choose anyone you like (Strahler in this case), and click OK.



After the process is complete, str_order will be added to the map document. Can you tell the order of the Cedar Creek watershed?

11.0 Stream to Feature

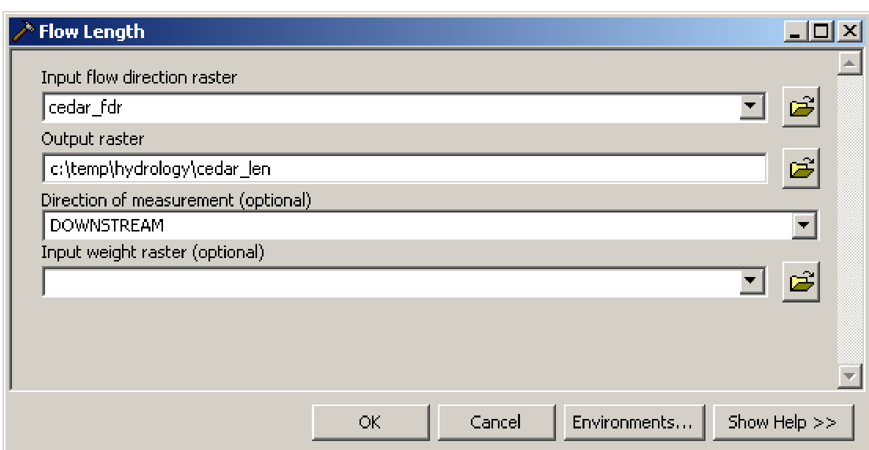
This tool converts stream raster to a polyline feature class. Provide stream as the input for stream raster, cedar_fdr as input for the flow direction raster and save the output as stream.shp in your working directory. Click OK.



After the process is complete, a shapefile named stream will be added to the map document. Save the map document. You can use this tool to create features from other stream related rasters such as stream order and stream link.

12.0 Flow Length

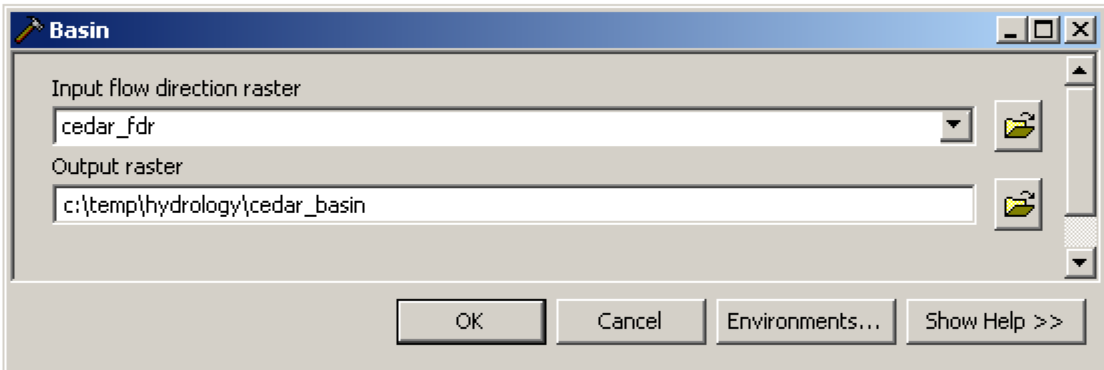
This tools uses the flow direction to compute the flow distance or length from each cell to the most downstream or upstream cell in the DEM. Double click on Flow Length. Provide cedar_fdr as the input flow direction raster and save the output as cedar_len in your working directory as show below. Use downstream to compute the flow length to the watershed outlet. Click OK.



After the process is complete, cedar_len will be added to the map document. What is the maximum distance any water drop has to travel over the cedar creek watershed to reach the outlet?

13.0 Basin

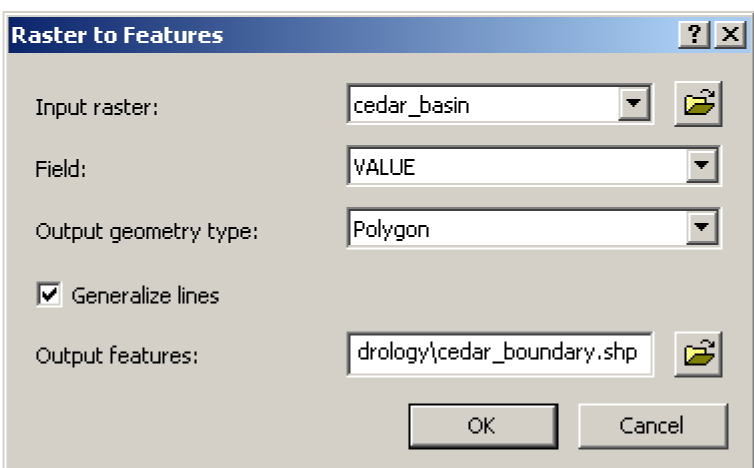
This tool uses the flow direction grid to find all sets of connected cells that belong to the same drainage basin, and assigns the number of cells that belong to a basin to all the cells within that basin. Double click on Basin. Produce cedar_fdr as the input flow direction raster and name the output raster as cedar_basin as shown below. Click OK.



After the process is complete, cedar_basin raster will be added to the map document. Although you will see a big drainage basin that gives the drainage boundary for cedar creek output, there are some small drainage areas that do not drain go the cedar outlet.

14.0 Creating Watershed Boundary

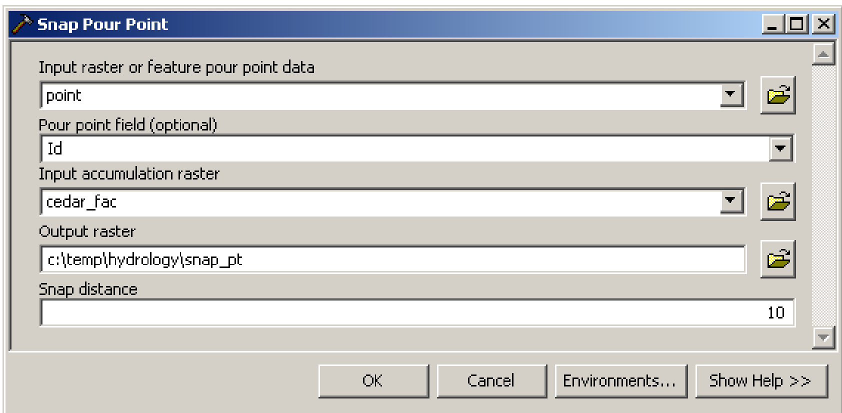
To get the boundary of for Cedar Creek watershed, convert basin raster to polygon features by selecting Spatial Analyst→Convert Raster to Features. Provide cedar_basin as the input raster, choose output geometry type as polygon (or polyline if you want), and save the output as cedar_boundary.shp in your working directory as shown below. Click OK.



After the process is complete, cedar_boundary shapefile will be added to the map document. Besides the main Creek Boundary, this shapefile also has small polygons that do not belong to Cedar Creek. You can delete these polygons if you want.

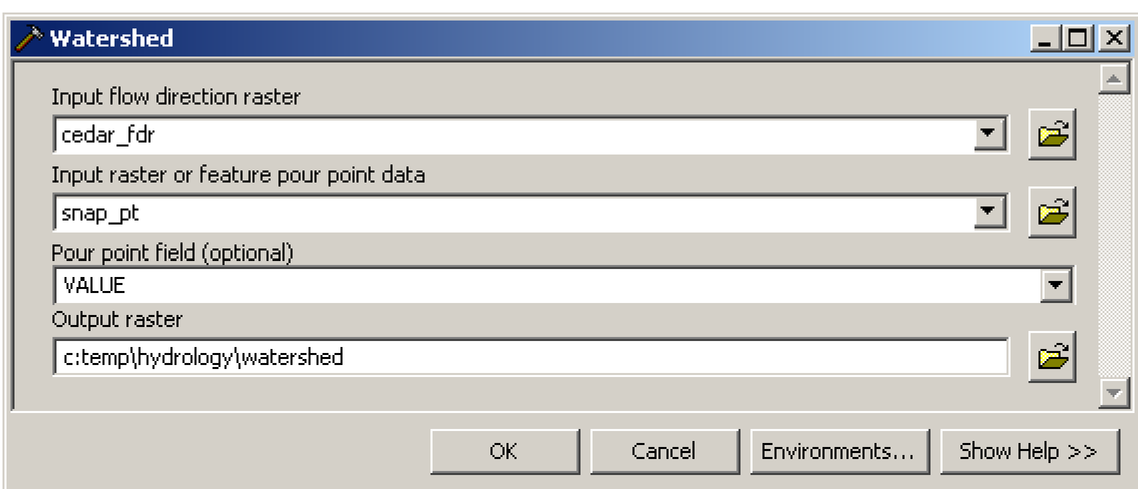
15.0 Delineating Sub-watersheds

In order to delineate subwatersheds, add the point shapefile in your map document. Although these points are snapped to the stream, it is a good idea to use the Snap Pour Point function to create grid of snapped points, and then use this grid to delineate sub watersheds. Double click on Snap Pour Point. Use the point shapefile as input for the feature pour point data, leave the default Id field unchanged for pour point field, use cedar_fac as input for the flow accumulation raster and name the output raster as snap_pt. Use a snap distance of 10m (this may change for different datasets and resolutions). Click OK.

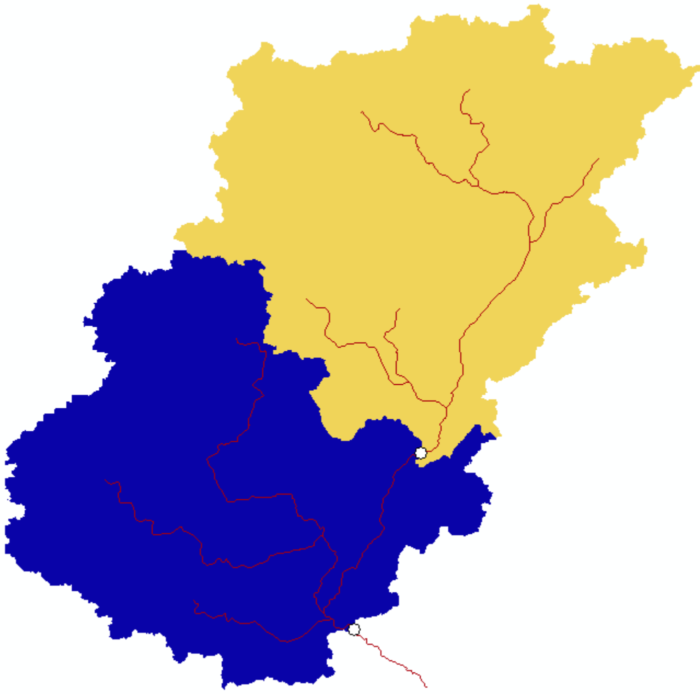


After the process is complete, a raster named snap_pt will be added to the map document. Zoom-in to the points to make sure that they align with the stream or flow accumulation grid.

Next, double click on Watershed. Use cedar_fdr as input for flow direction, snap_pt for input pour point raster, leave the default pour point field unchanged, and name the output raster as watershed. Click OK.



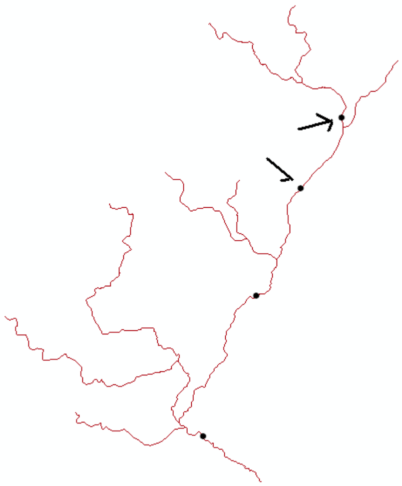
After the process is successfully completed, you should get a raster showing watersheds at these two points as shown below.



OK, you are done!

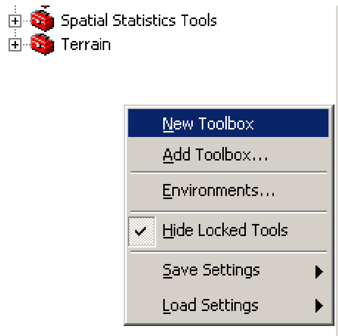
Do the following on your own and turn-in at the end of the class.

Add two more points to the point feature class (shown by arrows below), and recreate sub-watersheds using the Watershed tool. Turn-in your new map with these four sub-watersheds.

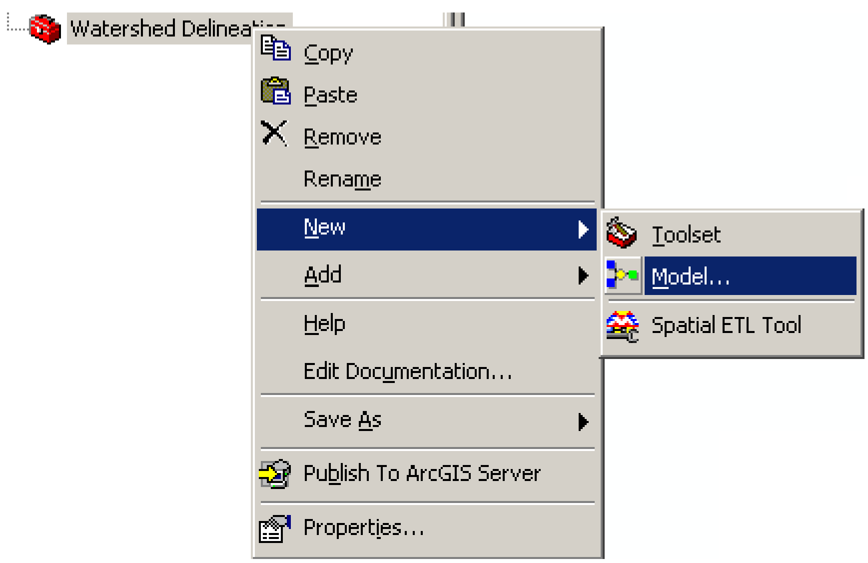


Creating a Model Builder Application

In order to create a model builder application, first create an empty toolbox by right-clicking in the "white" space in ArcToolbox, and selecting New Toolbox as shown below as shown below:

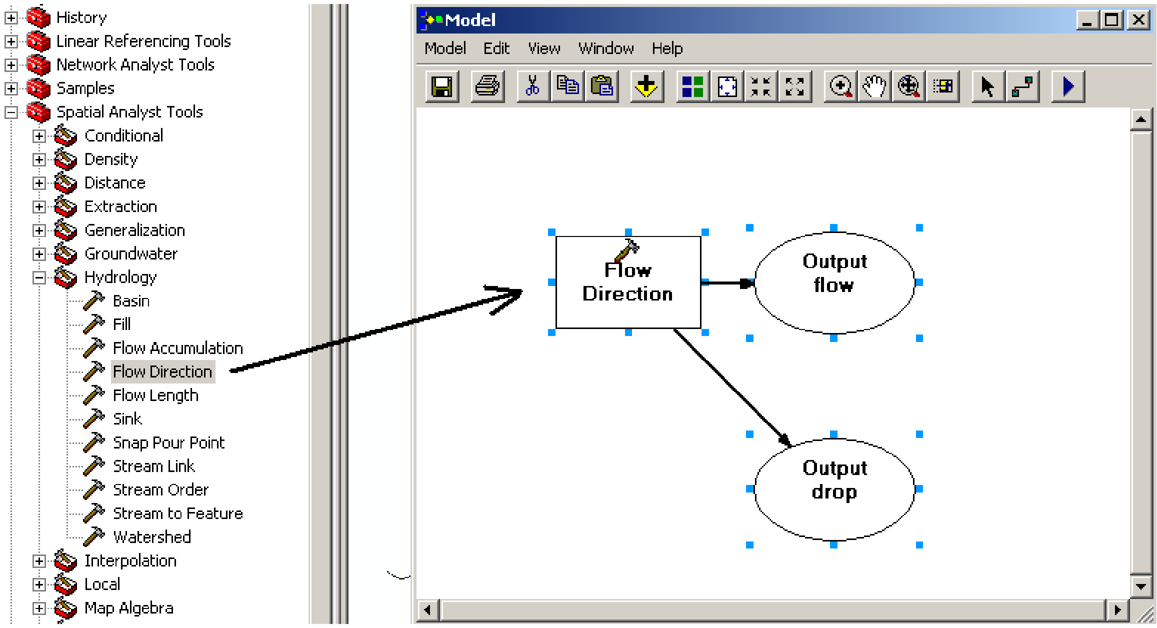


Rename the toolbox as Watershed Delineation. Right-click on Watershed Delineation toolbox and create a new Model as shown below.

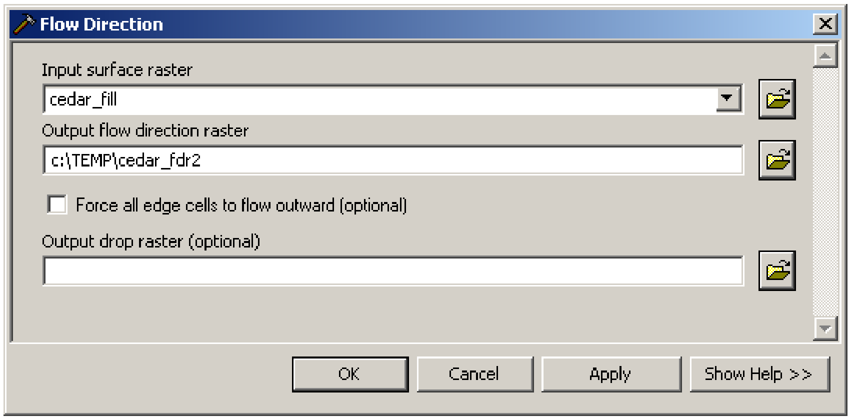


This will open the Model Builder interface in which you can create a workflow model by dragging toolbox from the ArcToolbox. Save the Model. Lets create a model that uses the filled DEM to create a flow direction raster.

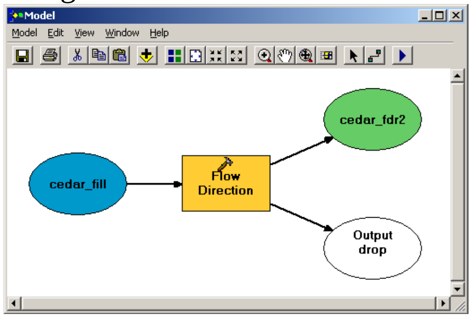
Drag the Flow Direction tool from ArcToobox in the Model interface to see the tool in the Model Builder interface as shown below.



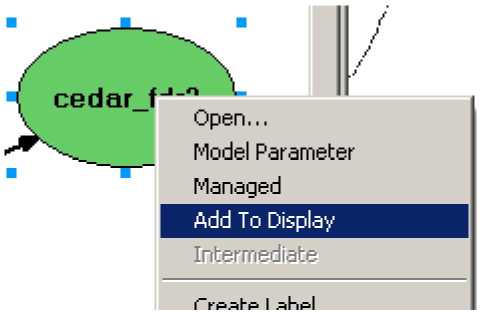
A rectangle (with the hammer) represents a tool, and a oval represents a input/output file. While colored box means that no input is provided to the tool. Double click on the Flow Direction rectangle to select cedar_fill as the input surface raster. Name the output flow direction raster as cedar_fdr2 (we already have cedar_fdr), and click OK (no need to specify the optional drop raster).



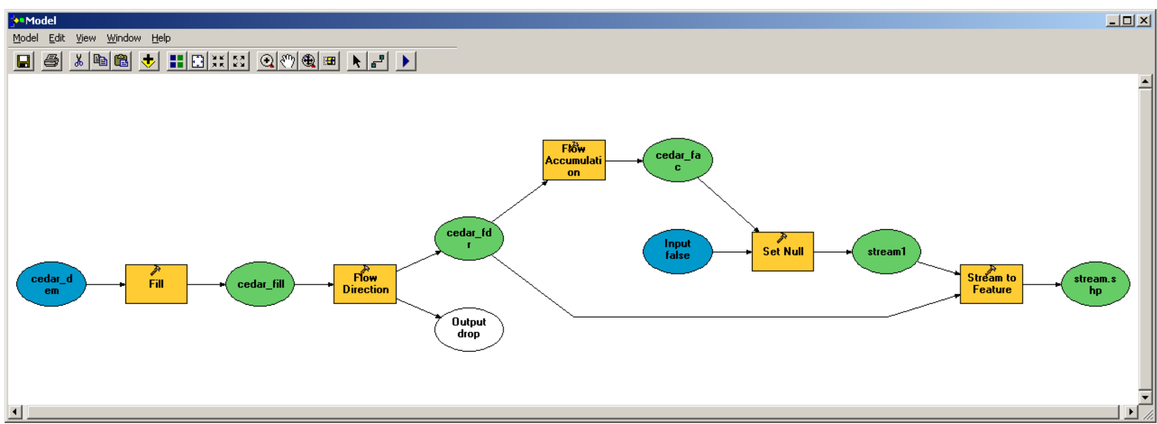
As soon as the input is provided, all the boxes (except the optional output drop) will change their color as shown below.



A toolbox is always yellow, a blue oval represents input to the model, and a green oval represents the output from the tool or the model. If you want, you can change these colors by right-clicking on them and selecting Display Properties. Similarly, you can make the model to add the final output or any intermediate outputs to the map document by right-clicking on the oval and selecting Add to Display as shown below.



Save the model. You can expand the model to perform flow accumulation and also the subsequent steps by dragging the tools from the ArcToolbox and providing appropriate inputs. A workflow to start with DEM and get the stream network is shown below.



You can run the model by either pushing the run button  or going to Model→Run Entire Model. Ok, you are done!!

Homework: Create a Model Builder application to generate stream network for Cedar Creek corresponding to 0.25%, 0.5%, 1%, 2%, 3%, 5%, 7.5% and 10% threshold area. Turn-in the following:

(1) Screen-shot of your model builder workflow
(2) Stream-networks corresponding to each threshold
(3) Stream order corresponding to each threshold
(4) Plot of total stream length versus % threshold
(5) Plot of drainage density versus % threshold
(6) Plot of bifurcation ratio versus % threshold